BEAM LOSS MONITORING IN THE ISIS SYNCHROTRON MAIN DIPOLE MAGNETS

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Abstract

Beam loss monitoring at the ISIS Neutron and Muon Source is primarily carried out with gas ionisation chambers filled with argon. Thirty-nine ionisation chambers are distributed evenly around the inner radius of the synchrotron, with additional devices for the linac and beam transport lines. To improve loss control, a programme has been implemented to install six scintillator Beam Loss Monitors (BLMs), each 300 mm long, inside each of the ten main dipole magnets of the synchrotron. Using these scintillator BLMs the accelerator can be fine-tuned to reduce areas of beam loss that were previously unseen or hard to characterise. Installation of the system is now complete and this paper reviews: the installation of the scintillator BLMs, the electronic hardware and software used to control them, and the initial measurements that have been taken using them.

INTRODUCTION

ISIS Beam Loss Monitoring

ISIS has two systems for beam loss detection: a main "global" system using thirty-nine argon filled ionisation chambers [1]; and a finer system, using BC-408 plastic scintillators, that provides additional monitoring in selected areas [2]. The gas ionisation chambers in the synchrotron are 3 m long and distributed evenly around the inner radius, about 2 m from the beam axis. As beam losses inside the synchrotron's main dipole magnets are shielded by the magnet yokes, they can be undetectable using the existing ionisation chambers. Therefore, to supplement these monitors, scintillator BLMs were initially installed inside the main dipole magnet downstream of the collimation straight, Dipole 2, as this had occasionally suffered beam related damage. This initial set of scintillators detected beam losses which were not measured on the ionisation chambers, and as such the decision was taken to install scintillators inside all ten of the main dipole magnets around the synchrotron. Each of the main dipole magnets is 4.4 m long, and for the initial set-up of Dipole 2, twelve BC-408 detectors were installed between the vacuum vessel and magnet yoke. Based on experience from Dipole 2, a configuration of six detectors has been installed in each of the main ring dipoles, which provided an optimal balance of cost, complexity and resolution. A key benefit of the scintillator detector design, with their entirely non-metallic construction, is that they avoid potentially serious problems with Eddy currents in the fast cycling ISIS magnets.

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System Overview

Figure 1 shows an outline of a scintillator system for one dipole, including main hardware, subsystems, locations, and connections.

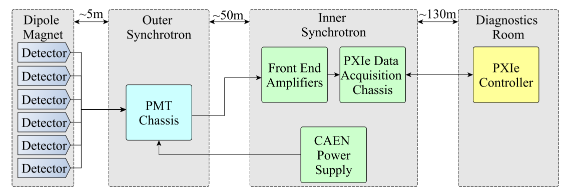

Figure 1: Overview of system hardware used for a single dipole.

As with the initial installation in Dipole 2, all detectors are installed within the main dipole magnets, between the magnet yoke and the vacuum vessel. All of the detector assemblies are installed on the inside radius of each dipole. Approximately 5 m from each dipole is a Photo Multiplier Tube (PMT) chassis holding six PMTs, one for each detector. The PMTs convert the light generated by the detectors into electrical "beam loss" signals. Each PMT is connected to a high voltage power supply and front end amplifiers, which are both located in the inner synchrotron area. This area is shielded by several metres of concrete, meaning radiation levels there are relatively low during accelerator operations. The CAEN power supply provides high bias voltages for each PMT. The front end amplifiers buffer the PMT outputs into a voltage which can be read by the PXIe data acquisition system.

Although the inner synchrotron area is shielded, some sensitive equipment, like the PXIe controller, can suffer from radiation-induced failure. Therefore, while the data acquisition cards for the system are located in the inner synchrotron area, the controller is located 100 m away, where radiation levels are negligible and access is unrestricted. The long distance connections between the two PXIe sub-systems is achieved with a custom optical fibre link, as detailed below.

DETECTORS

Detector Design

The detectors are based on the same design as those described in [2], based on BC-408 plastic scintillators. When high-energy particles interact with BC-408, light is generated [3]. The detector is covered in a light proof cover to eliminate background light, and connected to a PMT via optical fibres (see Fig. 2). As each detector has slightly different characteristics and responses, each detector and PMT pair is calibrated with a known radiation source in the lab prior to installation. The calibration voltages are then scaled to optimise the gain of each PMT.

Figure 2: BC408 scintillating detector and optical fibres with light proof covering, connected to a Photo Multiplier Tube (PMT).

Mounting and Installation

The detectors are screwed onto 300 mm fibreglass panels with polyaryletheretherketone (PEEK) screws and fibreglass mounts (see Fig. 3).

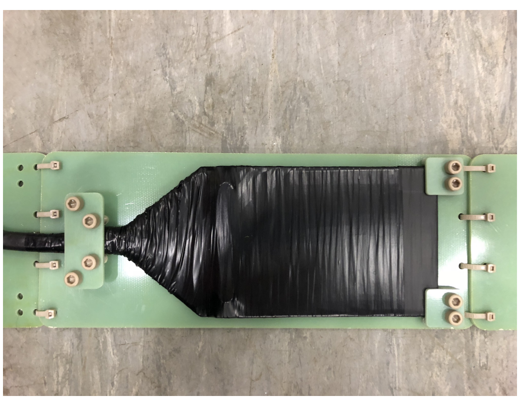

Figure 3: Detector mounted to fibreglass panel.

The scintillators are assembled in two sets of three, and each set is installed from opposite ends of the dipole on the inner circumference, between the magnet yoke and the vacuum vessel. To ensure that the detectors are equally spaced throughout the dipole, each 1.8 m assembly is made up of five panels, each 300 mm in length. Two of these serve as spacers between the detectors, and two additional, shorter 150 mm panels are attached to each end (see Fig. 4). All of the panels are connected using PEEK cable ties, to allow for some flexing during installation. PEEK was chosen as the material for the fastenings as it is non-metallic and resistant to ionising radiation [4]. Figure 4 shows the arrangement of the detectors inside the dipole. The half panels on the outside ends of the dipole make it easier to install and remove the detector assembly. Each dipole has a 19-inch chassis installed locally, which houses the PMTs for that dipole (see Fig. 5). Optical fibres trail out of each side of the dipole from the detectors to these PMTs. A patch panel is also housed inside this chassis, used for connecting the PMTs to the front end amplifiers and high voltage power supply.

Figure 5: Chassis to house PMTs for a single dipole.

FRONT END ELECTRONICS

High Voltage Power Supply

The PMTs are supplied with a variable bias voltage of ~1 kV, which controls the tube gain. Previous experience shows that these scintillators will discolour and their outputs will degrade with exposure to radiation. This degradation can be somewhat compensated for by increasing the gain on each PMT [2]. Ten of the twelve initial detectors installed in Dipole 2 provided useful data for ten years. Ultimately, their lifetimes were limited by fibre breakage rather than discolouration of the scintillating material. As each PMT and scintillator pair may need different gain levels, each of the sixty PMTs are supplied with independently adjustable voltage channels.

PMT bias voltages are provided by a CAEN power supply housed in the inner synchrotron. From here, bias cables are laid to each PMT chassis in the synchrotron hall. Even though the inner synchrotron area is shielded, previous CAEN power supplies suffered failures every one or two

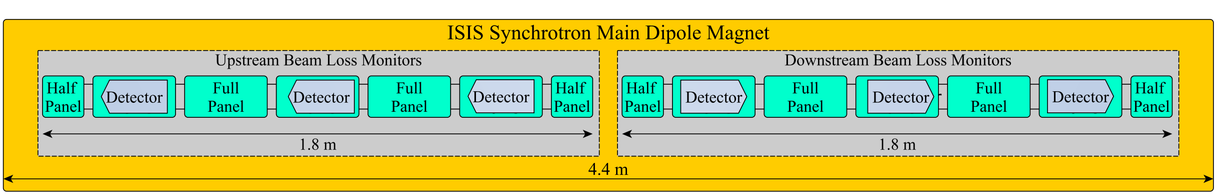

Figure 4: Arrangement of Beam Loss Monitors inside the dipole magnets (side view).

weeks during accelerator operation, which required a power cycle of the unit, or replacement of the damaged modules. To overcome this, 'rugged' power modules supplied by the manufacturer are now used instead of the off-the-shelf models. Since these new modules have been installed, there has been a significant reduction in the rates of failures, with the 'rugged' power supply requiring only a single power cycle in three months of operation.

Front End Amplifiers

Amplifiers with two stages are used to convert the current from each PMT into suitable voltages for the data acquisition system. The first stage, a transimpedance amplifier, is used to convert and amplify the signal. The second stage is a single order low pass filter, with a cut off frequency of 100 kHz, used to improve the signal to noise ratio of the output signal. The amplifiers are housed in a number of Eurocard PCBs. Each amplifier PCB has eight channels, routed through a backplane PCB to a connector card, which interfaces with the data acquisition system. Each amplifier channel is connected to a relay which can be enabled by a Digital Input/Output (DIO) line on the data acquisition system, allowing a calibration pulse to be fed into the amplifiers.

DATA ACQUISITION SYSTEM

Remote Controller for Radiation Tolerance

The ISIS Beam Diagnostics section has standardised on the National Instruments PXI platform for data acquisition [5]. A PXI chassis contains a controller and a number of data acquisition cards. The controller houses typical PC components such as a CPU and hard drive, whereas the data acquisition cards house the ADCs, DACs, and DIO. When these PXI systems were first installed in the inner synchrotron area, radiation levels regularly caused the controller's hard drives to fail. To avoid this, a MXI link was installed, to allow for the controller and data acquisition cards to be placed in separate chassis, connected together with an optical fibre cable of up to 200 m in length. The data acquisition cards remained in the inner synchrotron, and the controller was moved to the diagnostics room outside ionising radiation areas.

As this project requires data transfer rates beyond those supported by PXI systems, the newer PXIe platform was used. NI PCIe/PXIe-8735 MXIe cards and cables were used to connect a PXIe chassis to a rackmount controller RMC-8354. Instead of passive LC connectors, active CX4 to CX4 cables are required [6]. The maximum CX4 cable length officially supported by National Instruments is 100 m [6]. However, custom cables of 130 m length were built and tested. Back bone cables with Multi-fibre Termination Push-on (MTP) connectors were used at each end to connect to a patch panel at each location. MTP to CX4 cables are used from each patch panel to connect the two systems together. At the time of writing, this system has been in use for six months without issue.

Data Acquisition Cards

The PXIe chassis inside the inner synchrotron features a MXIe card to interface with the remote controller, and four National Instruments PXIe 6358 cards. Each 6358 card has sixteen analogue input channels and a number of DIO lines. Figure 6 shows the PXIe chassis and the 6358 cards connected to the front end amplifiers used for signal conditioning.

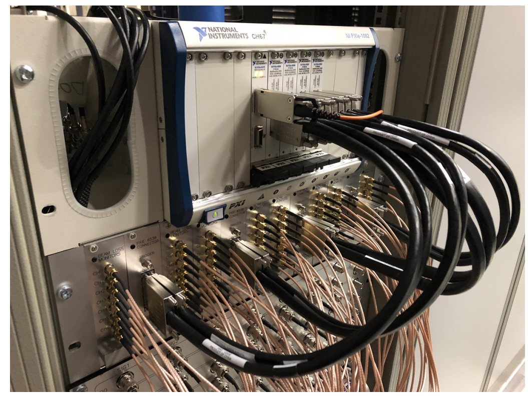

Figure 6: National Instruments PXIe system connected to front end Amplifiers.

The cards can sample up to a maximum rate of 1.25 MS/s. Data acquisition is triggered with every 50 Hz accelerator ramp, allowing for detailed beam loss data to be captured over the entire 10 ms cycle from injection to extraction.

APPLICATION SOFTWARE

Software Design

Data acquisition and display software has been developed in LabVIEW, and the DAQ software is deployed to the real-time RMC-8354 controller. The software acquires data from the acquisition cards and makes it available to the front end graphical user interface (GUI) via the TCP/IP protocol. It is also responsible for handling communication to the CAEN power supply server and the trigger timers on the ISIS control system: VISTA VSystem [7].

Graphical User Interface

Figure 7 shows the front panel of the LabVIEW user interface VI, developed to display live data from the scintillators. This VI has been built into an executable application stored on a network drive, which can be run from any Windows machine on the ISIS network. The VI receives data from the RMC-8354 and displays it as a histogram of the integrated loss on each monitor over each 10 ms acceleration cycle, and a sum of the loss from all monitors. More detailed graphs of the loss within each dipole, or on each individual detector channel, can also be viewed, and reference levels can be saved for each channel.

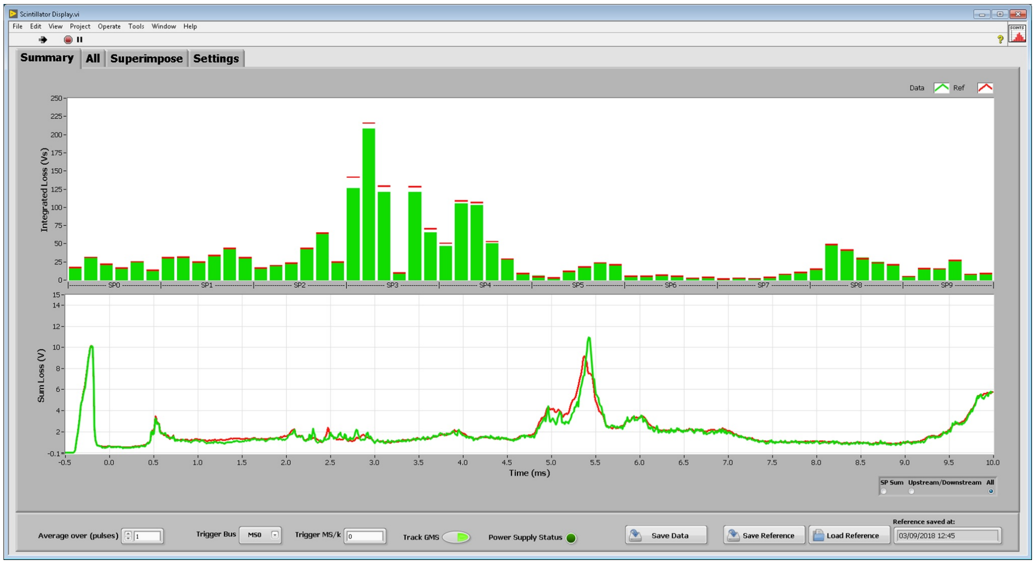

Figure 7: Scintillator Beam Loss Monitor GUI, showing loss in all ISIS dipoles.

CONCLUSION

Initial Performance and Future work

The program of installing new monitors into all of the main dipoles is now complete, and ISIS now has a beam loss monitoring system that will enable detailed machine tuning that was previously unavailable.

During the phased installation of the scintillators over multiple user cycles, radiation surveys showed reduced activation of those dipoles containing scintillators. As a result, synchrotron parameters will now be adjusted to minimise losses within all the main dipoles. With dipole losses accurately measured and minimised, the optimisation of the collimation system can now be reviewed and it may be possible to increase the machine acceptance and, potentially, increase operating beam intensity.

While all of the detectors and PMTs have been calibrated before installation, the detectors will degrade with prolonged radiation exposure. While this degradation can be somewhat compensated for by increasing the gain of the PMTs, accurate knowledge of the condition of each scintillator is unavailable. As the detector assembly itself may become activated, removal and recalibration of the detectors is not a practical solution. Instead, the dose received by each scintillator will be monitored with local total ionisation dosimeters and compared with separate characterisation measurements of detector degradation, performed by exposing a spare detector to a well-controlled dose [8].

REFERENCES

[1] M A Clarke-Gayther *et al.*, “Global Beam Loss Monitoring Using Long Ionisation Chambers at ISIS”, in *Proc. EPAC’94*, London, England, Jun.-Jul. 1994, pp. 1634–1636.

[2] S. J. Payne and S. A. Whitehead, “Fine Spatial Beam Loss Monitoring for the ISIS Proton Synchrotron”, in *Proc. EPAC’06*, Edinburgh, Scotland, Jun. 2006. pp. 1079–1081.

[3] Saint-Gobain Crystals, “BC-400, BC-404, BC-408, BC-412, BC-416 Premium Plastic Scintillators”, BC-408 datasheet, Feb. 2018.

[4] A. S. Vaughan and S. J. Sutton, "On radiation effects in oriented poly(ether ether ketone)", *Polymer*, vol. 36(8), pp. 1549-1554.

[5] S. J. Payne *et al.*, “Beam Diagnostics at ISIS”, in *Proc. HB’08*, Nashville, TN, USA, Aug. 2008. pp. 466–471.

[6] National Instruments, "Fiber-Optic MXI-Express x4 for PXI Express Series User Manual", NI PCIe-8735, NI PXIe-8735 user manual, Nov. 2009.

[7] B. Mannix and T. Gray, “Vista Controls Vsystem at the ISIS pulsed neutron facility”, presented at ICALEPCS’07, Knoxville, TN, USA, Oct. 2007, unpublished.

[8] D. M. Harryman and A. Pertica, "Online Total Ionisation Dosimeter (TID) Monitoring Using Semicondustor Based Radiation Sensors in the ISIS Proton Synchrotron", in *Proc. IBIC’16*, Barcelona, Spain, Sep 2016. `doi:10.18429/JACoW-IBIC2016-TUPG24`